Journal of Insan Mulia Education
E-ISSN: 2987-0585 | Vol. 4, No. 1, 2026
https://doi.org/10.59923/joinme.v4i1.760

Effectiveness of AR-Guided Inquiry E-Worksheets on Students' 21st-Century Skills in Science Lessons, Examined by Gender and Learning Style

M. Ibnusaputra[1),*], Putri Surya Damayanti[2)], Febriani[3)]

[1)]Department of Elementary School Teacher Education, STKIP Taman Siswa Bima, Bima, Indonesia
[2)]Department of Elementary School Teacher Education, STKIP Yapis Dompu, Dompu, Indonesia
[3)]Department of Physics, Universiti Pendidikan Sultan Idris, Tanjong Malim, Malaysia

*Correspondence: ibnusaputratsb@gmail.com

ABSTRAK

This study aims to analyze the effectiveness of using guided inquiry-based e-worksheets incorporating Augmented Reality (AR) on the development of students' 21st-century skills in science learning, as viewed through the lens of gender and learning style differences. The study employs a quantitative approach with a pretest–posttest control group quasi-experimental design. The research subjects were eighth-grade students at a public junior high school in Bima City, divided into an experimental group (using AR-based e-worksheets) and a control group (using conventional worksheets). Data were collected through critical thinking skill tests, observation sheets for collaboration, communication, and creativity, as well as a learning style questionnaire. Data analysis was conducted using ANOVA, GLM, Bonferroni post hoc tests, and n-gain scores. The results indicated that the implementation of AR-integrated guided inquiry e-worksheets significantly influenced the improvement of 21st-century skills (sig. = 0.008 < 0.05), with an average n-gain score of 65.38% (classified as moderately effective). Gender and learning style did not significantly influence learning outcomes, indicating that the learning process was inclusive and adaptive. The highest improvement occurred in creativity skills, followed by communication, collaboration, and critical thinking. These findings confirm that the integration of AR into inquiry-based learning creates a contextual, interactive, and reflective learning environment that supports the comprehensive development of 21st-century skills.

Kata Kunci: e-Worksheet Guided Inquiry; Augmented Reality; 21st-Century Skills; Learning Styles; Gender

INTRODUCTION

The need for educational innovation in the digital age is becoming increasingly urgent. As times change and the industrial revolution progresses, developments in the world of education are also evident. Adaptation by stakeholders in the education sector has become crucial in this rapidly evolving landscape. This is particularly important for enhancing students' 21st-century skills (Artacho et al., 2020; Bonfield et al., 2020). These skills include critical, creative, collaborative, and communicative thinking, which form a vital foundation for addressing global challenges and the rapid pace of technological advancement (Kennedy & Sundberg, 2020). These four key pillars enable students to actively participate in a global society fraught with complex challenges. Learning oriented toward mastering these skills not only strengthens individual competitiveness but also fosters the adaptive and innovative character necessary to face the uncertainties of the future. This expectation positions education in the digital age not merely as a transfer of knowledge but as a process that must cultivate higher-order thinking skills and social competencies grounded in the critical and responsible use of technology.

Science education should address 21 st-century needs through practical and contextual approaches, not only theoretical instruction. As a subject that develops scientific thinking and problem-solving skills, science has strong potential to foster critical thinking, creativity, collaboration, and effective communication through authentic learning experiences. Connecting scientific concepts to everyday phenomena helps students understand the relevance of science to social and environmental issues. Therefore, innovative learning models and technology-assisted approaches, such as project-based learning, digital experiments, and contextual learning, are essential to strengthen science education and prepare students to become capable and competitive learners in the digital era. Despite the growing emphasis on twenty-first century competencies, science learning remains largely teacher-centered and offers limited opportunities to develop communication, collaboration, creativity, and critical thinking. Abstract concepts and conventional worksheets further restrict engagement, highlighting the need for innovative, inquiry-based, and contextual learning approaches. One approach that can be applied to develop these skills is the *guided inquiry* learning model. Through this approach, students are guided to actively discover and construct their understanding through a series of questions and explorations led by the teacher (Dwi Hatria et al., 2024; Sejati et al., 2021; Treagust et al., 2020). According to Sarumaha (2022), this model is highly suitable for science education, which demands scientific processes and active student engagement. This is because it emphasizes scientific processes and active student involvement in discovering concepts. Activities such as formulating problems, developing hypotheses, conducting experiments, and analyzing and communicating observation results provide students with the opportunity to directly experience the scientific thinking process.

This study is grounded in constructivist learning theory, Multimedia Learning Theory, and Inquiry Learning Theory to explain how augmented reality-assisted guided inquiry develops students' twenty-first century skills. Constructivism emphasizes active knowledge construction through problem-solving and direct learning experiences (Almulla, 2023; Vijayakumar Bharathi & Pande, 2025). Guided inquiry supports this through systematic investigation with teacher guidance. Multimedia Learning Theory explains that AR improves understanding by combining verbal explanations with dynamic visual representations, helping students process abstract science concepts more effectively (Çeken & Taşkın, 2022; C. H. Chen, 2020). AR visualization also strengthens reasoning, communication, and critical thinking. Inquiry Learning Theory highlights questioning, hypothesis formation, evidence-based investigation, and conclusion drawing as essential scientific processes (Arifin et al., 2025; F. Chen & Chen, 2025). Together, these theories position AR-assisted guided inquiry as a pedagogical approach that promotes collaboration, problem-solving, critical thinking, and scientific literacy.

To support the effectiveness of the *guided inquiry* approach, the use of innovative learning materials is crucial. Digital *e-worksheets* have emerged as a modern learning solution capable of increasing student participation and supporting flexible learning. When *e-worksheets* are equipped with *Augmented Reality* (AR) technology, the student learning experience becomes more realistic, visual, and interactive (Dewi, Ambiyar, et al., 2024; Dewi, Kurani, et al., 2024). According to İbili (2020) and Isnaeni and Sa'diyah (2024), AR allows students to view and interact with 3D objects that represent abstract concepts in science. This can aid students' visual understanding and increase the appeal of learning. The combination of *guided inquiry* and AR in *e-worksheets* has the potential to create a learning environment that is both challenging and enjoyable.

The effectiveness of implementing a learning model is also influenced by individual student factors, such as gender and learning style. Gender can influence interest, engagement, and learning preferences (Aguillon et al., 2020; Tumbularani & Diana, 2024). Meanwhile, learning styles such as visual, auditory, and kinesthetic influence how students receive and process information (Djara et al., 2023; Shihab et al., 2023). It is important to understand how differences in gender and learning styles can affect the effectiveness of using AR-based *e-worksheets* in science education. There may be significant differences between male and female students in their responses to the instructional model. Additionally, certain learning styles may be better suited to specific instructional approaches.

Although augmented reality and inquiry-based learning have been widely studied in science education, most research focuses on achievement, motivation, and conceptual understanding without considering individual learner characteristics. Limited attention has been given to the interaction of gender and learning styles in AR-supported inquiry learning, especially in elementary science. This creates a theoretical gap because AR effectiveness depends on how students process information and engage with visual-spatial tasks. Gender may influence participation and confidence, while learning styles affect how students understand scientific concepts (Idrizi et al., 2023). This study extends previous research by examining both the effectiveness of AR-assisted inquiry learning and the contribution of gender and learning styles to science learning outcomes, providing a more inclusive pedagogical framework.

Several studies have examined the integration of AR in *e-worksheet-guided inquiry*. However, few of these studies have analyzed the findings from the perspective of individual differences, particularly gender and learning styles. In fact, an approach that takes into account student characteristics will result in more inclusive and adaptive learning (Saputra & Stiawan, 2024; Strielkowski et al., 2024). By understanding the influence of gender and learning styles, teachers can design more effective differentiated learning strategies (Gibon et al., 2020). Therefore, this study aims to: (1) examine the effectiveness of augmented reality-assisted guided inquiry e-worksheets in improving students' twenty-first century skills in science learning; (2) analyze whether differences in gender influence learning outcomes; (3) investigate the contribution of learning styles to students' twenty-first century skill development; and (4) evaluate the extent to which AR-supported inquiry learning provides an inclusive and adaptive learning environment for diverse learner characteristics.

METHOD

This study employs a quantitative approach with a quasi-experimental design. The study followed four stages: pretest, learning style identification, intervention, and posttest with observational evaluation. This design was chosen because the researcher sought to determine the effectiveness of using *AR-based guided inquiry e-worksheets* on students' 21st-century skills, while considering moderator variables such as gender and learning style. This study employs *a pretest-posttest control group design*, consisting of an experimental group using AR-based *e- worksheets* and a control group using conventional *e-worksheets* without AR content. The AR medium used is adapted from Julkifli et al. (2025). The population for this study comprises all eighth-grade students at one of the public junior high schools in Bima City with an age range of 14-15 years. The sample was selected using *purposive sampling*, considering the availability of technological resources and the active involvement of science teachers. Two classes were selected as the sample one class as the experimental group with 22 students, and one class as the control group with 21 students. The intervention was conducted for one consecutive week during regular science learning sessions, consisting of two meetings. The experimental group received guided inquiry learning supported by augmented reality-based e-worksheets, while the control group was taught using conventional guided inquiry methods without augmented reality integration. To maintain consistency of instruction and reduce teacher-related bias, both groups were taught by the same science teacher using the same learning objectives, curriculum content, and lesson duration.

Data collection was conducted using the following instruments: (1) A critical thinking skills test, consisting of 8 open-ended questions representing each indicator. (2) A learning style questionnaire, using a modified version of the VARK Questionnaire to identify each student's learning style. (3) A learning activity observation sheet, containing 15 statements to assess students' levels of communication, collaboration, and creativity skills. The indicators for each 21st-century skill, along with the test items or observation statements, can be referred to in Table 1.

Table 1. Research Instrument Outline

21st-Century Skills	Indicators	Test/Observation Statement
Communication Skills	1. Conveys ideas clearly, both orally and in writing. 2. Conveying information based on data or evidence. 3. Using digital communication tools appropriately. 4. Listening and responding to opinions effectively	Observation statement: 1. Students express their opinions clearly. 2. Students use media to support their ideas. 3. Students pay attention to and respond to their peers. 4. Students use facts or data when expressing opinions
Collaboration Skills	1. Work effectively in groups. 2. Actively contributing to shared tasks. 3. Respecting others' opinions. 4. Resolving conflicts productively.	Observation statement: 1. Students demonstrate active cooperation. 2. Students participate in completing group tasks. 3. Students listen to and respect the ideas. 4. Students are able to resolve disagreements peacefully.
Creative thinking skills	1. Generating original ideas to solve problems. 2. Developing innovative solutions. 3. Using various approaches in experiments. 4. Combining information to create new concepts.	Observation statements: 1. Students present unique or previously unconsidered ideas 2. Students propose new and different ways to complete tasks. 3. Students try different approaches to solve problems 4. Students combine various pieces of information to create a product or idea.

21st-Century Skills	Indicators	Test/Observation Statement
Critical Thinking Skills	1. Ability to identify problems. 2. Analyzing information logically. 3. Constructing valid arguments. 4. Drawing appropriate conclusions based on data.	Test: 1. Identify independent, dependent, and control variables in a simple science experiment. 2. Explaining the cause-and-effect relationship of a scientific phenomenon based on observational data. 3. Formulating a hypothesis appropriate to a contextual problem (effect of light on plant growth). 4. Interpreting graphs or tables of experimental results and relating them to relevant scientific concepts. 5. Identifying logical errors or incorrect assumptions in experimental results. 6. Argue based on experimental evidence to support or reject a hypothesis. 7. Comparing two sets of observational data to determine the most rational result. 8. Drawing valid scientific conclusions based on empirical evidence and theory.

Data analysis techniques for the pretest and posttest results were analyzed using descriptive and inferential statistics. Normality and homogeneity tests were conducted as prerequisites for the analysis. Subsequently, Spearman's rank correlation test was used to determine the effect of implementing AR-based *e-worksheets* on students' 21st-century skills. ANOVA was used to determine differences in the effect of media use on students' 21st-century skills when examined by gender and learning style. If a significant interaction was found, it was followed by post hoc tests. Furthermore, the Rash model was analyzed using WinStep to determine the difficulty level of the test instrument. Finally, the n-gain score test was used to determine the effectiveness of implementing AR-based *guided inquiry e-worksheets*.

RESULTS AND DISCUSSION

One-way ANOVA

The first analysis was used to determine differences in 21st-century skills scores among students due to the implementation of AR-based electronic worksheets using a guided learning approach. The results are shown in Table 2.

Table 2. Results of the Pre-test–Post-test ANOVA for Critical Thinking Skills

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Skor Pretest	Between Groups	6.061	1	6.061	2.789	.103
	Within Groups	89.102	41	2.173		
Skor Posttest	Between Groups	30.625	1	30.625	7.750	.008
	Within Groups	162.026	41	3.952		

Referring to Table 2, there is a difference in 21st-century skills scores among students due to the implementation of AR-based guided inquiry e-worksheets. This finding is indicated by a significant value of <0.05 (0.008) on the posttest scores, whereas the pretest showed no significant. Further post hoc ANOVA tests are required on the posttest data; however, a homogeneity test is required as a prerequisite. The results of the homogeneity test are presented in Table 3.

Table 3. Results of the Homogeneity Test for 21st-Century Skills Scores

Test of Homogeneity of Variances				
	Levene Statistic	df1	df2	Sig.
Communication	.381	2	40	.686
Collaboration	2.149	2	40	.130
Creativity	2.311	2	40	.112
Critical	1.506	2	40	.234

Table 3 shows that the posttest data for 21st-century skills in both research classes are homogeneous, so a Bonferroni post hoc ANOVA test can be used. The results are shown in Table 4.

Table 4. Results of the Posttest ANOVA for 21st-Century Skills

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Communication	Between Groups	1.813	2	.906	2.214	.122
	Within Groups	16.373	40	.409		
Collaboration	Between Groups	1.142	2	.571	1.298	.284
	Within Groups	17.602	40	.440		
Creativity	Between Groups	3.728	2	1.864	8.271	**.001**
	Within Groups	9.016	40	.225		
Critical	Between Groups	.264	2	.132	.184	.833
	Within Groups	28.713	40	.718		

Based on Table 4, the implementation of AR-integrated e-worksheet guided inquiry resulted in alignment of 21st-century skills specifically communication, collaboration, and critical thinking when examined in terms of learning styles. In contrast, creativity skills showed significant differences.

The implementation of augmented reality (AR)-based e-worksheet guided inquiry has a positive impact on 21st-century skills, particularly in communication, collaboration, and critical thinking, and is relatively consistent across various learning styles. Students with visual, auditory, and kinesthetic learning styles demonstrated balanced achievement in all three skills following this innovative media-based learning approach. This reinforces the assumption that the integration of AR into guided inquiry can provide a multisensory and contextual learning experience, thereby facilitating diverse learning needs (C. H. Chen & Chu, 2024; Crogman et al., 2025).

Guided inquiry places students at the center of learning and provides space for exploration, observation, and the development of understanding through the scientific process. Combining guided inquiry with AR technology makes learning more concrete and interactive, enabling effective collaboration and communication among students as they explore the material. According to Rasyid Ridlo et al. (2024), the inquiry approach not only develops conceptual understanding but also scientific process skills closely related to critical thinking. At the same time, AR technology, with its additional layer of spatial visualization and interactive simulations, strongly supports students with visual and kinesthetic learning styles (Alvarez-Marin & Velazquez-Iturbide, 2021; Lin et al., 2024; Wang et al., 2024).

In contrast to creativity skills, there are significant differences among learning styles in the development of this aspect. Students with kinesthetic and visual learning styles tend to demonstrate greater creativity than those with auditory learning styles. This is explained by Fleming's VAK theory, which states that visual and kinesthetic learners benefit more from image-based learning materials and direct interaction. The learning context with AR provides a hands-on experience in manipulating virtual objects, which can inspire students to generate original ideas and solve problems creatively (K. Lee et al., 2020). Conversely, students with an auditory learning style may struggle to fully express their creativity because the primary stimuli in AR media are visual and motion-based, rather than sound or lengthy narration. Research by Alvarez-Marin & Velazquez-Iturbide (2021) states that the success of AR media depends heavily on how its multimedia elements are accessed by users, and research by Huang et al. (2020) indicates that if AR is not tailored to learning preferences, its effects may be uneven or lead to significant differences. To determine whether or not there are significant differences, a post hoc test was used, the results of which are presented in Table 5.

Table 5. Post Hoc Test Results

Multiple Comparisons						
Dependent Variable		Learning Style	Learning Style	Mean Difference	Std. Error	Sig.
Communication	Bonferroni	Audio	Visual	**.47368**	.23028	.139
			Kinesthetic	.18182	.26210	1.000
		Visual	Audio	-.47368	.23028	.139
			Kinesthetic	-.29187	.24240	.707
		Kinesthetic	Audio	-.18182	.26210	1.000

Multiple Comparisons						
Dependent Variable		Learning Style	Learning Style	Mean Difference	Std. Error	Sig.
			Visual	.29187	.24240	.707
Collaboration	Bonferroni	Audio	Visual	-.37652	.23877	.368
			Kinesthetic	-.14685	.27176	1.000
		Visual	Audio	.37652	.23877	.368
			Kinesthetic	-.22967	.25132	1.000
		Kinesthetic	Audio	.14685	.27176	1.000
			Visual	**.22967**	.25132	1.000
Creativity	Bonferroni	Audio	Visual	.04196	.17088	.003
			Kinesthetic	**-.61134***	.19450	1.000
		Visual	Audio	-.04196	.17088	.003
			Kinesthetic	-.56938*	.17987	.009
		Kinesthetic	Audio	-.61134*	.19450	1.000
			Visual	.56938*	.17987	.009
Critical	Bonferroni	Audio	Visual	-.18219	.30495	1.000
			Kinesthetic	-.07692	.34709	1.000
		Visual	Audio	**.18219**	.30495	1.000
			Kinesthetic	.10526	.32099	1.000
		Kinesthetic	Audio	.07692	.34709	1.000
			Visual	-.10526	.32099	1.000

*. The mean difference is significant at the 0.05 level.

The visual results in the form of a graph from the post hoc ANOVA (Bonferroni) test above are shown in Figure 1.

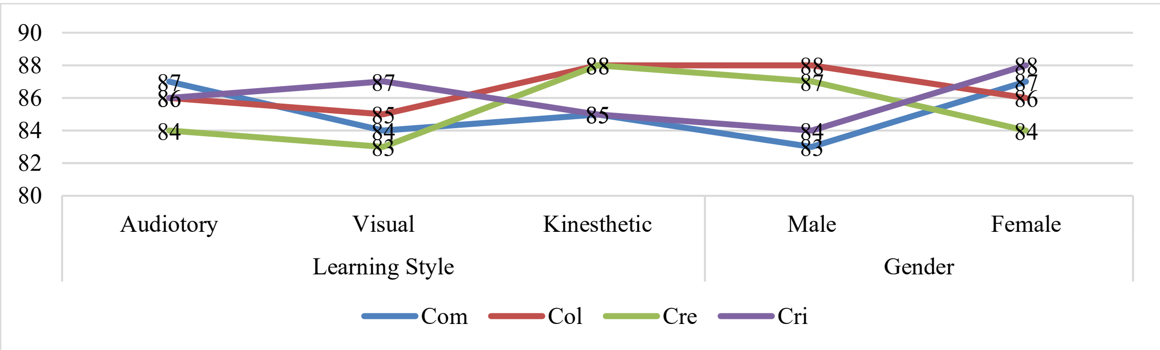

Figure 1. Comparison of Students' 21st-Century Skills by Learning Style and Gender

Referring to Table 5 and Figure 1, female students with an auditory learning style outperformed their peers in communication skills. Next, male students with a kinesthetic learning style outperformed their peers in collaboration skills. Female students with a visual learning style excelled in critical thinking skills. Finally, male students with a kinesthetic learning style outperformed their peers in creativity skills. Students with an auditory learning style are more responsive to information presented orally or in the form of discussions and narratives. In the implementation of *e-worksheet guided inquiry*, problem-solving or idea-exploration sessions typically involve verbal interaction with both groupmates and the teacher. This is an advantage for auditory learners, who naturally possess the ability to listen actively and express ideas verbally in a more expressive manner, thereby fostering the development of communication skills. Research by Kossyvaki & Curran (2020) also reinforces that technology-based learning environments incorporating narration, music, or verbal interaction can significantly enhance the creativity and communication skills of auditory learners. Consequently, although *Augmented Reality (AR)* media are predominantly visual, when combined with verbal activities in *guided inquiry*, auditory learners can actually demonstrate high performance.

In contrast, students with a visual learning style demonstrate higher achievement in collaboration and critical thinking. This is explained by the characteristics of AR, which provides 3D object visualizations, interactive simulations, and spatial data presentation all of which align well with visual learning preferences. When students engage in AR-based observation and exploration activities, they gain the opportunity to analyze, compare, and interpret visuals a tangible manifestation of critical thinking skills. In guided inquiry, students are asked to observe, formulate problems, collect data, and draw conclusions. This process is highly visual when combined with AR, as visual learners grasp patterns, relationships, and structures more quickly through graphical displays or visual models. According to Girwidz & Kohnle (2021), *Multimedia Learning* theory emphasizes that visualization in digital media strengthens the connection between verbal and nonverbal representations, thereby enhancing cognitive processing and supporting higher-order thinking skills.

Furthermore, collaboration skills in the context of AR use encourage students to help one another operate or understand visualizations, which strengthens the role of visual learners within the group. They are able to guide discussions based on visual interpretations, which then becomes an active contribution to the group collaboration process. Research by Sudirman et al. (2025) shows that the use of AR in collaborative learning enhances coordination, visual-based discussions, and joint problem-solving, which greatly supports visual learners.

GLM Test

The GLM test is used to find out whether the innate factors of the dependent variable, namely 21st-century skills, also have an influence on treatment. The results are shown in Table 6.

Table 6. Results of the GLM Test of 21st-Century Skills by Learning Style and Gender

Tests of Between-Subjects Effects						
Source	Dependent Variable	df	Mean Square	F	Sig.	Partial Eta Squared
Gender	Communication	1	.104	.230	.634	.006
	Collaboration	1	.002	.004	.948	.000
	Creativity	1	.604	1.997	.166	.049
	Critical	1	.451	.685	.413	.017
Learning Style	Communication	1	.243	.539	.467	.014
	Collaboration	1	.074	.209	.650	.005
	Creativity	1	.019	.063	.803	.002
	Critical	1	.040	.060	.808	.002

The results of the GLM test shown in Table 6 indicate that the implementation of AR-based e-worksheet guided inquiry has been able to align all 21st-century skills regardless of students' gender or learning style. This statement is supported by the significant values for each skill being >0.05. It is further evidenced by the relatively very small *partial eta-squared* values, meaning that gender and learning styles do not influence learning outcomes when using AR-based e-worksheet guided inquiry. This condition indirectly indicates that the implementation of this learning approach is capable of accommodating and facilitating differences in students' gender and learning styles. Gender showed no significant effect because the learning design provided equal access, participation opportunities, and instructional support for all students regardless of gender. The use of guided inquiry with Augmented Reality created a collaborative and student-centered environment where both male and female students engaged in the same tasks, used the same digital resources, and received similar teacher guidance. At the junior high school level, differences in science achievement are often more strongly influenced by learning experiences and classroom interaction than by gender itself (Ekatushabe et al., 2021). The technology-supported inquiry process minimized traditional gender stereotypes in science learning by focusing students on exploration, discussion, and problem-solving rather than competition, resulting in relatively similar learning outcomes across gender groups.

Level of Difficulty of Students' 21st-Century Skills

First, the difficulty levels of students' 21st-century skills are presented based on skill indicators, ranging from the easiest to hardest for students answer or meet. The results are shown in Figure 2.

```
----------------------------------------------------------------------------------------------
|ENTRY   TOTAL  TOTAL     JMLE    MODEL|   INFIT    |  OUTFIT   |PTMEASUR-AL|EXACT  MATCH|        |      |
|NUMBER  SCORE  COUNT  MEASURE   S.E.  |MNSQ   ZSTD|MNSQ   ZSTD|CORR.   EXP.| OBS%   EXP%|DISPLACE| Item |
|--------------------------------------+-----------+-----------+-----------+------------+--------+------|
|     4      3     43     1.18     .62| .92   -.03| .80   -.22|  .36    .28| 88.5   88.4|     .01| Cri  |
|     2      7     43      .09     .46| .98   -.03| .97   -.02|  .44    .42| 73.1   72.9|     .01| Col  |
|     1     10     43     -.47     .42| .96   -.21| .96   -.21|  .52    .50| 69.2   66.6|     .01| Com  |
|     3     12     43     -.81     .41|1.11   1.04|1.11   1.06|  .47    .55| 53.8   62.4|     .00| Cre  |
|--------------------------------------+-----------+-----------+-----------+------------+--------+------|
| MEAN     8.0   43.0      .00     .48| .99    .19| .96    .15|            | 71.2   72.6|     .00|      |
| P.SD     3.4     .0      .76     .09| .07    .49| .11    .53|            | 12.3    9.9|     .00|      |
----------------------------------------------------------------------------------------------
```
Figure 2. Level of Difficulty of Students' 21st-Century Skills

Based on Figure 2 above, the critical thinking skill indicators were the most difficult for students to meet or answer. Meanwhile, the easiest to answer or meet were the creativity and communication skill indicators. In contrast, collaboration skills were assumed to fall into the moderate category in terms of students' ability to meet them. Further examination is needed regarding the difficulty levels of students' 21st-century skills based on their research class, gender, and learning style. The results are shown in Figure 3 below.

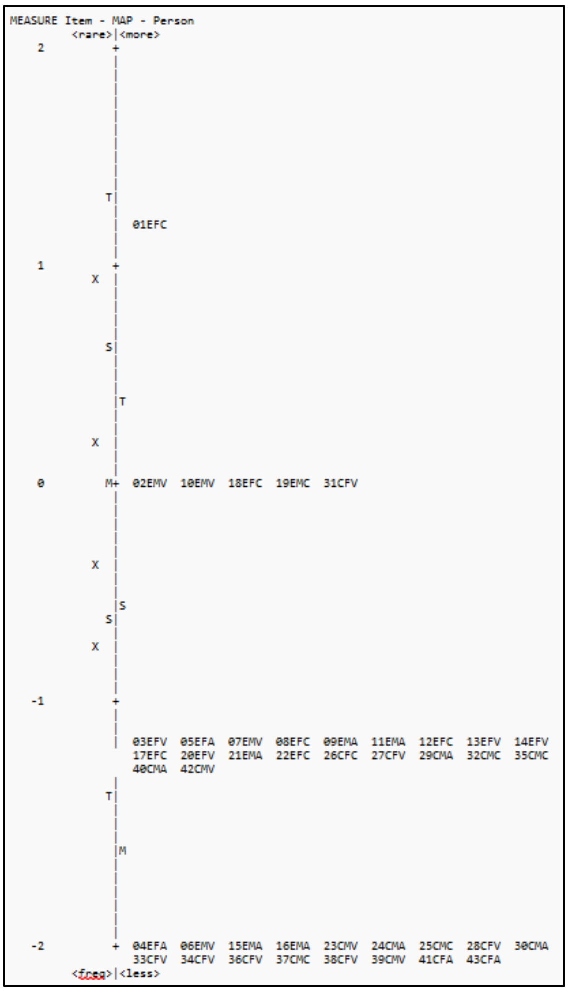

Figure 3. Level of Difficulty of 21st-Century Skills by Learning Style and Gender

Referring to Figure 3 above, female students with a kinesthetic learning style in the experimental class (01EFC) demonstrated the highest/most advanced 21st-century skills. They were followed by students from classes 02EMV, 10EMV, 18EFC, 19EMC, and 31CFV, who also demonstrated the highest/most advanced 21st-century skills. Based on the general distribution, students in the experimental class outperformed those in the control class. This finding suggests that the implementation of AR-based e-worksheet guided inquiry is capable of enhancing students' 21st-century skills.

N-gain score

The results of the N-gain test were used to determine the category of improvement in the value of AR-based e-worksheet guided inquiry learning treatment in experimental classes when reviewed from 3 facts, namely class, gender, and learning style. The results are shown in Table 7.

Table 7. Results of the N-Gain Score Test for 21st-Century Skills

	Research Class		Statistic
N Gain (%)	Experiment	Mean	65.3785
	Control	Mean	37.8058
	Gender		Statistic
N Gain (%)	Female	Mean	58.9545
	Male	Mean	54.5356

	Learning Style		Statistic
N Gain (%)	Audio	Mean	53.0264
	Visual	Mean	59.0901
	Kinesthetic	Mean	57.2902

The results of the n-gain score test (Table 7) show that the average improvement in 21st-century skills in the experimental class was 65.38% (moderately effective), which is significantly higher than that of the control class, which was classified as less effective. These results indicate that the implementation of AR-based e- worksheet guided inquiry is quite effective in improving students' 21st-century skills compared to conventional e-worksheet guided inquiry. Further analysis by gender revealed that the implementation of AR-based e-worksheet guided inquiry was more effective in improving 21st-century skills among female students, with a "fairly effective" rating (58.95%). Research by Hyde (2024) indicates that gender differences in learning outcomes are actually small; however, in certain contexts (such as more communicative or collaborative methods), female students tend to be more responsive. The final analysis regarding students' learning styles revealed that students with a visual learning style showed the most significant improvement in 21st-century skills due to the implementation of AR-based e-worksheet guided inquiry, with a "moderately effective" rating (59.09%). This aligns with Fleming's VARK Learning Modalities theory, which states that learning effectiveness can be enhanced when methods are tailored to students' learning styles. Since the implementation of learning media is visual in nature, students with a visual learning style will find it easier to understand and absorb the material.

The Effectiveness of *Augmented Reality*-Based *E-Worksheet Guided Inquiry* on 21st-Century Skill

The results of the study indicate that the implementation of Augmented Reality (AR)-based guided inquiry e-worksheets is effective in enhancing students' 21st-century skills in science education. This effectiveness is evident from the increase in the n-gain score, which reached an average of 65.38% in the experimental class (classified as "moderately effective"), far exceeding the control class's score of 37.80% (classified as "less effective"). These findings indicate that the integration of AR into e-worksheets is capable of creating a more meaningful, interactive, and contextual learning experience, which supports the simultaneous development of communication, collaboration, critical thinking, and creativity skills (Ekawati et al., 2018; Yanto et al., 2024).

From a theoretical perspective, guided inquiry emphasizes the scientific thinking process through the stages of exploration, problem formulation, hypothesis testing, and drawing conclusions (Asmoro et al., 2021; Wen et al., 2020). When this model is combined with AR technology, students do not merely act as recipients of information, but as discoverers and creators of knowledge. The visualization of 3D objects in AR bridges abstract science concepts to make them more concrete, thereby facilitating the formation of cognitive connections between theory and real-world phenomena. This aligns with the views of Wei et al. (2020) and Lee et al. (2024), who state that the integration of AR in science learning enhances conceptual understanding, as students engage in spatial observation and exploration based on direct experience.

ANOVA analysis confirms this effectiveness. A significance value of 0.008 (<0.05) for the posttest scores indicates that there was a significant difference between the experimental and control groups after the intervention was administered. This finding indicates that AR-enhanced e-worksheet guided inquiry significantly improves 21st-century skills compared to conventional learning. Post hoc tests revealed a dominant difference in creativity skills, while communication, collaboration, and critical thinking were relatively comparable. This suggests that while all aspects improved, the visual and interactive stimuli of AR had the strongest impact on the development of students' creativity. These findings align with the research by Martín-Mariscal et al. (2025) and Kumar & Agarwal (2025), which confirm that AR-based media stimulate divergent thinking by providing space for free exploration, object manipulation, and the testing of new ideas. In the context of guided inquiry, such exploration is guided by a structured scientific framework, ensuring that creativity does not develop randomly but is directed toward solving real-world problems. Consequently, AR functions not only as a visualization tool but also as a cognitive amplifier that expands students' capacity for creative thinking.

Interestingly, the results of the GLM analysis showed that gender and learning style did not have a significant effect (sig. >0.05) on learning effectiveness. This means that AR-based e-worksheet guided inquiry is inclusive and adaptive to individual differences. The very small partial eta-squared value confirms that variations in outcomes are more determined by the quality of interaction with the media and the inquiry process, rather than by biological differences or learning preferences. This supports the principle of student-centered learning that good digital media can balance the diversity of student characteristics (Bhardwaj et al., 2025; Zhao et al., 2022). Nevertheless, descriptive analysis reveals an interesting pattern: female students with an auditory learning style tend to excel in communication, while male students with a kinesthetic learning style stand out in collaboration and creativity. These findings can be explained by VARK theory, which states that learning effectiveness increases when instructional media align with an individual's dominant learning modality. AR provides a multisensory experience that balances visual and kinesthetic needs, yet auditory learners still benefit from verbal interaction during group inquiry discussions, scientific arguments, and reflection on results (Shihab et al., 2023). The success of AR in the context of guided inquiry is not solely due to visualization, but because it integrates into a collaborative social learning system.

Another interesting finding is that the difficulty level of 21st-century skills indicators shows that critical thinking remains the most challenging aspect for students, while creativity and communication are easier to achieve. This indicates that although AR can enhance visual exploration and creative ideas, the development of critical thinking still requires reflective guidance and the reinforcement of metacognitive processes. Lim (Supriadi et al., 2023). emphasizes that effective inquiry must prioritize the reflection phase and the justification of arguments based on data, rather than merely exploring phenomena. Therefore, the integration of AR should be accompanied by scaffolding of analytical questions so that students are not merely captivated by visual displays but are also encouraged to rationally assess and evaluate scientific evidence.

Creativity emerged as the most improved aspect because the guided inquiry e-worksheet supported by Augmented Reality provided students with opportunities to explore scientific concepts through open-ended investigation and visual experimentation. Unlike conventional worksheets that often emphasize fixed procedures and single correct answers, AR-assisted inquiry allowed students to manipulate objects, observe multiple possibilities, and generate their own interpretations of scientific phenomena (Mansour et al., 2025). This learning environment encouraged divergent thinking, curiosity, and idea generation, which are central components of creativity. The interactive visualization of abstract science concepts also reduced cognitive barriers, enabling students to focus more on exploration and problem-solving rather than memorization, thereby strengthening creative engagement during the learning process.

Based on the n-gain scores by learning style, the highest improvement was found among visual learners (59.09%), followed by kinesthetic learners (57.29%) and auditory learners (53.02%). This confirms that the predominance of visual elements in AR provides an advantage for visual learners. However, the relatively balanced results across the three learning styles indicate that this medium is sufficiently universal for various types of students. This effectiveness is also reflected in gender differences: although female students achieved a higher average increase (58.95%) compared to male students (54.53%), the difference was not statistically significant. This means that AR successfully provides an equitable learning experience that is not gender-biased, reinforcing Lo et al (2021) finding that gender-based differences in learning outcomes tend to be small when instructional design is collaborative and participatory.

In general, the integration of AR-enhanced e-worksheet-guided inquiry has proven to be effective, inclusive, and adaptable to student characteristics. It not only improves cognitive outcomes but also fosters soft skills such as scientific communication and teamwork. Learning becomes more contextual because students can directly connect scientific concepts with reality as visualized through AR. Several pedagogical factors explain these findings, particularly the structured nature of guided inquiry and the support of Augmented Reality visualization. Guided inquiry provided clear stages such as questioning, investigation, observation, analysis, and conclusion, helping students think scientifically and systematically. AR made abstract concepts more concrete and accessible, increasing students' confidence and participation. Teacher scaffolding ensured students stayed focused and received guidance when facing difficulties. In addition, collaborative group work encouraged discussion and idea exchange, creating a learning environment that supported creativity, critical thinking, and equal participation among students.

This study has several limitations, including a small sample of 43 eighth-grade students from one junior high school, which may limit the generalizability of the findings. The short intervention period may not fully reflect the long-term effects of AR-assisted guided inquiry learning, and the use of self-report questionnaires for learning styles may introduce subjectivity. Despite these limitations, the study shows that guided inquiry supported by augmented reality can improve creativity, collaboration, and scientific understanding. For practical implementation, teachers should select science topics involving abstract concepts and design AR-based worksheets that guide students through inquiry stages such as observing, questioning, analyzing, and concluding. Effective implementation also requires teacher training in both technical and pedagogical aspects, as well as adequate school facilities, including internet access, mobile devices, and technological infrastructure, to support sustainable classroom practice.

CONCLUSION

This study demonstrates that augmented reality-assisted guided inquiry e-worksheets are effective in improving students' twenty-first century skills in science learning. Statistical findings showed a significant difference in posttest performance between the experimental and control groups, with an average n-gain score of 65.38%, indicating moderate effectiveness. Among the assessed dimensions, creativity showed the greatest improvement, followed by communication, collaboration, and critical thinking. The findings also indicate that gender and learning style did not significantly influence learning outcomes, suggesting that the instructional design was sufficiently inclusive and adaptive across different student characteristics. Although descriptive differences appeared across groups, these variations were not statistically meaningful. These findings suggest that integrating guided inquiry with augmented reality provides a contextual and interactive learning environment that supports active knowledge construction and the development of higher-order competencies. Therefore, AR-assisted inquiry-based e-worksheets may serve as a promising instructional alternative for science education, particularly for strengthening students' twenty-first century skills through technology-supported and student-centered learning.

REFERENCES

Aguillon, S. M., Siegmund, G. F., Petipas, R. H., Drake, A. G., Cotner, S., & Ballen, C. J. (2020). Gender differences in student participation in an active-learning classroom. *CBE Life Sciences Education*, *19*(2). https://doi.org/10.1187/cbe.19-03-0048

Almulla, M. A. (2023). Constructivism learning theory: A paradigm for students' critical thinking, creativity, and problem solving to affect academic performance in higher education. *Cogent Education*, *10*(1). https://doi.org/10.1080/2331186X.2023.2172929

Alvarez-Marin, A., & Velazquez-Iturbide, J. A. (2021). Augmented Reality and Engineering Education: A Systematic Review. *IEEE Transactions on Learning Technologies*, *14*(6), 817–831. https://doi.org/10.1109/TLT.2022.3144356

Arifin, Z., Sukarmin, S., Saputro, S., & Kamari, A. (2025). The effect of inquiry-based learning on students' critical thinking skills in science education: A systematic review and meta-analysis. *Eurasia Journal of Mathematics, Science and Technology Education*, *21*(3). https://doi.org/10.29333/ejmste/15988

Artacho, E. G., Martínez, T. S., Ortega Martín, J. L., Marín Marín, J. A., & García, G. G. (2020). Teacher Training in Lifelong Learning—The Importance of Digital Competence in the Encouragement of Teaching Innovation. *Sustainability*, *12*(7), 2852. https://doi.org/10.3390/SU12072852

Asmoro, S. P., Suciati, & Prayitno, B. A. (2021). Empowering Scientific Thinking Skills of Students with Different Scientific Activity Types through Guided Inquiry. *International Journal of Instruction*, *14*(1), 947–962. https://doi.org/10.29333/iji.2021.14156a

Bhardwaj, V., Zhang, S., Tan, Y. Q., & Pandey, V. (2025). Redefining learning: student-centered strategies for academic and personal growth. *Frontiers in Education*, *10*, 1518602. https://doi.org/10.3389/FEDUC.2025.1518602

Bonfield, C. A., Salter, M., Longmuir, A., Benson, M., & Adachi, C. (2020). Transformation or evolution?: Education 4.0, teaching and learning in the digital age. *Higher Education Pedagogies*, *5*(1), 223–246. https://doi.org/10.1080/23752696.2020.1816847

Çeken, B., & Taşkın, N. (2022). Multimedia learning principles in different learning environments: a systematic review. In *Smart Learning Environments* (Vol. 9). Springer. https://doi.org/10.1186/s40561-022-00200-2

Chen, C. H. (2020). Impacts of augmented reality and a digital game on students' science learning with reflection prompts in multimedia learning. *Educational Technology Research and Development*, *68*, 3057–3076. https://doi.org/10.1007/s11423-020-09834-w

Chen, C. H., & Chu, Y. R. (2024). VR-assisted inquiry-based learning to promote students' science learning achievements, sense of presence, and global perspectives. *Education and Information Technologies*, *29*(15), 19421–19441. https://doi.org/10.1007/S10639-024-12620-3

Chen, F., & Chen, G. (2025). Learning analytics in inquiry-based learning: a systematic review. *Educational Technology Research and Development*, *73*, 2131–2161. https://doi.org/10.1007/s11423-025-10507-9

Crogman, H. T., Cano, V. D., Pacheco, E., Sonawane, R. B., & Boroon, R. (2025). Virtual Reality, Augmented Reality, and Mixed Reality in Experiential Learning: Transforming Educational Paradigms. *Education Sciences*, *15*(3), 303. https://doi.org/10.3390/EDUCSCI15030303

Devika, S. V, Arvind, A., Kaur, R., & Anupama, A. (2024). From Lecture-Based Learning to Problem-Based Learning: A Review on Navigating the Transformation in Engineering Education. *Journal of Engineering Education Transformations*, *38*(Special Issue 1), 179–183. https://doi.org/10.16920/jeet/2024/v38is1/24229

Dewi, I. P., Ambiyar, Mursyida, L., Effendi, H., Giatman, M., Efrizon, Hanafi, H. F., & Ali, S. K. (2024). Virtual Reality in Algorithm Programming Course: Practicality and Implications for College Students. *JOIV : International Journal on Informatics Visualization*, *8*(3–2), 1720–1727. https://doi.org/10.62527/JOIV.8.3-2.3113

Dewi, I. P., Kurani, R., Setiawan, H., & Kabatiah, M. (2024). Innovative laboratory learning: a study evaluating the practicality of integrated e-worksheets with augmented reality in electrical machines course. *International Journal of Information and Education Technology*, *14*(7), 996–1005. https://doi.org/10.18178/ijiet.2024.14.7.2127

Djara, J. I., Imaniar, M., Sae, E., & Anin, S. (2023). Pengaruh Gaya Belajar Terhadap Hasil Belajar Siswa. *Jurnal Pendidikan Dan Kebudayaan (JURDIKBUD)*, *3*(2), 226–233. https://doi.org/10.55606/jurdikbud.v3i2.1907

Dwi Hatria, J., Vrasetya, A., Yulia, P., Matematika, P., & Kerinci, I. (2024). Efektivitas Penggunaan Model Pembelajaran Inquiry Pada Materi Teorema Phytagoras Terhadap Siswa SMPN 2 Sungai Penuh. *PRAXIS: Jurnal Pengabdian Kepada Masyarakat*, *3*(2), 171–180. https://doi.org/10.47776/PRAXIS.V3I2.802

Ekatushabe, M., Kwarikunda, D., Muwonge, C. M., Ssenyonga, J., & Schiefele, U. (2021). Relations between perceived teacher's autonomy support, cognitive appraisals and boredom in physics learning among lower secondary school students. *International Journal of STEM Education*, *8*. https://doi.org/10.1186/s40594-021-00272-5

Ekawati, R., Fiangga, S., & Siswono, T. Y. E. (2018). Historical aspect of mathematics on Indonesian mathematics textbook. In A. B. D. Nandiyanto & A. G. Abdullah (Eds.), *IOP Conference Series: Materials Science and Engineering* (Vol. 434, Number 1). Institute of Physics Publishing helen.craven@iop.org. https://doi.org/10.1088/1757-899X/434/1/012001

Gibon, T., Ph, G., Candidate, . D, & Chen, X. (2020). Teacher Educators' Perspectives and Experiences towards Differentiated Instruction. *International Journal of Instruction*, *13*(4), 781–798. https://doi.org/10.29333/iji.2020.13448a

Girwidz, R., & Kohnle, A. (2021). Multimedia and Digital Media in Physics Instruction. *Challenges in Physics Education*, 297–336. https://doi.org/10.1007/978-3-030-87391-2_11

Huang, C. L., Luo, Y. F., Yang, S. C., Lu, C. M., & Chen, A. S. (2020). Influence of Students' Learning Style, Sense of Presence, and Cognitive Load on Learning Outcomes in an Immersive Virtual Reality Learning Environment. *Journal of Educational Computing Research*, *58*(3), 596–615. https://doi.org/10.1177/0735633119867422

İbili, E., Çat, M., Resnyansky, D., Şahin, S., & Billinghurst, M. (2020). An assessment of geometry teaching supported with augmented reality teaching materials to enhance students' 3D geometry thinking skills. *International Journal of Mathematical Education in Science and Technology*, *51*(2), 224–246. https://doi.org/10.1080/0020739X.2019.1583382

Idrizi, E., Filiposka, S., & Trajkovikj, V. (2023). Gender impact on STEM online learning- a correlational study of gender, personality traits and learning styles in relation to different online teaching modalities. *Multimedia Tools and Applications*, *82*, 30201–30219. https://doi.org/10.1007/s11042-023-14908-x

Isnaeni, N., & Sa'diyah, C. (2024). Mengoptimalkan Kemampuan Literasi Sains dengan Earth Exploration: E-Modul Berbasis Augmented Reality Berbantuan Assemblr EDU. *Proceeding Seminar Nasional IPA*, 521–530. https://proceeding.unnes.ac.id/snipa/article/view/3733

Julkifli, F., Hardiansyah, H., & Hakim, A. R. (2025). The Influence of Augmented Reality (Ar) Media on The Learning Outcomes of SMP Negeri 2 Woha Students in Ict Subjects. *Journal of Educational Sciences*, *9*(5), 4594–4607. https://doi.org/10.31258/JES.9.5.P.4594-4607

Kennedy, T. J., & Sundberg, C. W. (2020). 21st Century Skills. *Science Education in Theory and Practice*, 479–496. https://doi.org/10.1007/978-3-030-43620-9_32

Kossyvaki, L., & Curran, S. (2020). The role of technology-mediated music-making in enhancing engagement and social communication in children with autism and intellectual disabilities. *Journal of Intellectual Disabilities*, *24*(1), 118–138. https://doi.org/10.1177/1744629518772648

Kumar, H., & Agarwal, M. N. (2025). Filtering the reality: Exploring the dark and bright sides of augmented reality–based filters on social media. *Australian Journal of Management*, *50*(1), 152–172. https://doi.org/10.1177/03128962231199356

Lee, K., Malerba, F., & Primi, A. (2020). The Fourth Industrial Revolution, Changing Global Value Chains and Industrial Upgrading in Emerging Economies. *Journal of Economic Policy Reform*, 359–370. https://doi.org/10.1080/17487870.2020.1735386

Lee, T., Wen, Y., Chan, M. Y., Azam, A. B., Looi, C. K., Taib, S., Ooi, C. H., Huang, L. H., Xie, Y., & Cai, Y. (2024). Investigation of virtual & augmented reality classroom learning environments in university STEM education. *Interactive Learning Environments*, *32*(6), 2617–2632. https://doi.org/10.1080/10494820.2022.2155838

Lin, L., Bai, S., Qu, M., Wei, X., Wang, L., Wu, F., Liu, B., Zhou, W., & Kuruoğlu, E. E. (2024). Transformer-Based Light Field Geometry Learning for No-Reference Light Field Image Quality Assessment. *IEEE Transactions on Broadcasting*, *70*(2), 597–606. https://doi.org/10.1109/TBC.2024.3353579

Lo, J. H., Lai, Y. F., & Hsu, T. L. (2021). The Study of AR-Based Learning for Natural Science Inquiry Activities in Taiwan's Elementary School from the Perspective of Sustainable Development. *Sustainability*, *13*(11), 6283. https://doi.org/10.3390/SU13116283

Mansour, N., Aras, C., Staarman, J. K., & Alotaibi, S. B. M. (2025). Embodied learning of science concepts through augmented reality technology. *Education and Information Technologies*, *30*, 8245–8275. https://doi.org/10.1007/s10639-024-13120-0

Martín-Mariscal, A., Torres-Leal, C., Aguilar-Planet, T., & Peralta, E. (2025). The Role of Virtual and Augmented Reality in Industrial Design: A Case Study of Usability Assessment. *Applied Sciences 2025, Vol. 15, Page 8725*, *15*(15), 8725. https://doi.org/10.3390/APP15158725

Rasyid Ridlo, Z., Jember, U., Kalimantan No, J., & Tegalboto, K. (2024). Pengaruh Penerapan Model Inkuiri Dengan LKPD Berbasis Diagram Berpikir Multidimensi Terhadap Keterampilan Proses Sains Dan Hasil Belajar Siswa Dalam Pembelajaran IPA. *Jurnal Wahana Pendidikan*, *11*(1), 149–156. https://doi.org/10.25157/JWP.V11I1.13164

Saputra, A. A., & Stiawan, A. (2024). Kajian Review Kurikulum K13 dan Kurikulum Merdeka dalam Implikasinya Terhadap Pembelajaran di Masa Mendatang. *SOSEARCH : Social Science Educational Research*, *5*(1), 1–17. https://doi.org/10.26740/sosearch.v5n1.p1-17

Sarumaha, M., & Harefa, D. (2022). Model Pembelajaran Inquiry Terbimbing Terhadap Hasil Belajar IPA Terpadu Siswa. *Ndrumi : Jurnal Ilmu Pendidikan Dan Humaniora*, *5*(1), 27–36. https://doi.org/10.57094/NDRUMI.V5I1.517

Sejati, A., Sejati, A. E., Syarifuddin, S., Nasruddin, N., Miftachurohmah, N., Nursalam, L. O., & Hariyanto, E. (2021). The Effectiveness of Guided Inquiry Learning Model with Edmodo Assisted to Facilitate Critical Thinking Skills. *Prisma Sains : Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan IPA IKIP Mataram*, *9*(2), 204–219. https://doi.org/10.33394/j-ps.v9i2.4260

Shihab, S. R., Sultana, N., & Samad, A. (2023). Pedagogy Designing With Augmented Reality: a Paradigm Shift in Educational Approaches. *Interdiciplinary Journal and Hummanity (INJURITY)*, *2*(11), 878–892. https://doi.org/10.58631/INJURITY.V2I11.136

Strielkowski, W., Grebennikova, V., Lisovskiy, A., Rakhimova, G., & Vasileva, T. (2024). AI-driven adaptive learning for sustainable educational transformation. *Sustainable Development*, *33*(2), 1921–1947. https://doi.org/10.1002/SD.3221

Sudirman, S., Rodríguez-Nieto, C., Adi, P., Bukhori Muslim, A., Faizah, S., Dwi Susandi, A., & Sa'dijah, C. (2025). Contextualising AR digital module instruction as artifacts in 3D geometry: a didactical tetrahedron action research. *International Journal of Mathematical Education in Science and Technology*. https://doi.org/10.1080/0020739X.2025.2530957

Supriadi, S., Robiansyah, F., Wardana, D., Yunia, Y., & Syahda, N. (2023). Didactical design integer operation number of sundanese ethnomathematics online during Covid 19 pandemics with Endog-Endogan games in pre-service elementary school students. In Sugianto, K. Shimizu, E. Cahyono, Masturi, C. P. Lim, & S. Aazmi (Eds.), *AIP Conference Proceedings* (Vol. 2614). American Institute of Physics Inc. https://doi.org/10.1063/5.0125833

Treagust, D. F., Qureshi, S. S., Vishnumolakala, V. R., Ojeil, J., Mocerino, M., & Southam, D. C. (2020). Process-Oriented Guided Inquiry Learning (POGIL) as a Culturally Relevant Pedagogy (CRP) in Qatar: a Perspective from Grade 10 Chemistry Classes. *Research in Science Education*, *50*(3), 813–831. https://doi.org/10.1007/S11165-018-9712-0

Tumbularani, T., & Diana, R. R. (2024). Analisis Peran Gender Terhadap Perbedaan Minat Dan Partisipasi Anak Dalam Pembelajaran STEAM. *As-Sibyan: Jurnal Pendidikan Anak Usia Dini*, *9*(1), 85–100. https://doi.org/10.32678/ASSIBYAN.V9I1.9969

Vijayakumar Bharathi, S., & Pande, M. B. (2025). Does constructivism learning approach lead to developing creative thinking skills? The mediating role of online collaborative learning environments. *Journal of Computers in Education*, *12*, 551–587. https://doi.org/10.1007/s40692-024-00321-2

Wang, S., Zhao, M., Ding, W., Yang, Q., Li, H., Shao, C., Wang, B., & Liu, Y. (2024). Ecological Suitability Evaluation of City Construction Based on Landscape Ecological Analysis. *Sustainability (Switzerland)*, *16*(21). https://doi.org/10.3390/su16219178

Wen, C. T., Liu, C. C., Chang, H. Y., Chang, C. J., Chang, M. H., Fan Chiang, S. H., Yang, C. W., & Hwang, F. K. (2020). Students' guided inquiry with simulation and its relation to school science achievement and scientific literacy. *Computers & Education*, *149*, 103830. https://doi.org/10.1016/J.COMPEDU.2020.103830

Yanto, D. T. P., Ganefri, Sukardi, Yanto, J. P., Kurani, R., & Muslim. (2024). Engineering Students' Acceptance of Augmented Reality Technology Integrated with E-Worksheet in The Laboratory Learning. *International Journal of Online & Biomedical Engineering*, *20*(3), 39. https://doi.org/10.3991/IJOE.V20I03.46101

Zhao, E., He, J., Jin, Z., & Wang, Y. (2022). Student-Centered Learning Environment Based on Multimedia Big Data Analysis. *Mobile Information Systems*, *2022*(1), 9572413. https://doi.org/10.1155/2022/9572413